Internal and Emergency Medicine
https://doi.org/10.1007/s11739-024-03756-8

IM - REVIEW

Ultrasound for body composition assessment: a narrative review

Raquel Marín Baselga[1] · Francisco Javier Teigell-Muñoz[2] · José M. Porcel[3] · Javier Ramos Lázaro[4] · Samuel García Rubio[5]

Received: 31 July 2024 / Accepted: 21 August 2024

Abstract

Ultrasound has become an increasingly valuable tool for the assessment of body composition, offering several applications and indications in clinical practice. Ultrasound allows bedside evaluation of muscle mass, fat compartments, and extravascular water, providing a cost-effective, portable, and accessible alternative to traditional methods, such as Dual-energy X-ray Absorptiometry (DEXA), Bioelectrical Impedance Analysis (BIA), Computed Tomography (CT), and Magnetic Resonance Imaging (MRI). It is particularly useful in evaluating conditions, such as malnutrition, sarcopenia, and sarcopenic obesity, which require poor muscle mass to establish a diagnosis. The potential uses of ultrasound in body composition assessment include measurement of muscle thickness, cross-sectional area, pennation angle, and echo-intensity, which are indicative of muscle health. Additionally, ultrasound can be used to evaluate various fat compartments, including visceral, subcutaneous, and ectopic fat, which are important for understanding metabolic health and cardiovascular risk. However, the widespread adoption of ultrasound is challenged by the lack of standardized measurements and the absence of ultrasound measures in the validated diagnostic criteria. This article reviews the current applications of ultrasound in body composition assessment, highlighting the recent advancements and the correlation between ultrasound parameters and clinical outcomes. It discusses the advantages of ultrasound while also addressing its limitations, such as the need for standardized protocols and cut-off points. By providing a comprehensive update based on recent publications, this article aims to enhance the clinical utility of ultrasound in assessing and monitoring body composition and pave the way for future research in this field.

Keywords Ultrasound · body composition · muscle mass · sarcopenia · fat tissue

Introduction (Compartment theory)

Body composition can be assessed from the molecular to the macroscopic level. The simplest way to divide the human body is into two major compartments: fat mass and lean mass, which include bone and muscle. A commonly used model in clinical practice is the 5-compartment model, which divides the lean soft tissue compartment into water, skeletal muscle mass, and organs [1]. The various body compartment models are shown in Fig. 1.

Malnutrition is associated with increased risk of disease [2]. Patients diagnosed with sarcopenia, as defined by the European Working Group on Sarcopenia in Older People 2 (EWGSOP2) [3] or those who are at risk due to treatments received, are at an increased risk of falls, fractures, disability, hospital admissions, and mortality [4, 5]. Sarcopenia is a muscle disease that is characterized by low muscle strength, quantity, or quality. Additionally, ectopic fat accumulation (visceral, hepatic, or cardiac) is associated with a higher risk of adverse cardiovascular outcomes [6]. The European Society for Clinical Nutrition and Metabolism (ESPEN) and the American Society for Parenteral and Enteral Nutrition (ASPEN) provide guidelines that recommend the routine assessment of body composition, with a particular emphasis on lean mass [7, 8]. The Global Leadership Initiative on Malnutrition

✉ Samuel García Rubio
samuel.garciarubio@osakidetza.eus

1 Internal Medicine Department, Hospital Universitario La Paz, Madrid, Spain

2 Internal Medicine Department, Hospital Universitario Infanta Cristina, Parla, Spain

3 Internal Medicine Department, Hospital Universitario Arnau Vilanova, IRBLleida, Lleida, Spain

4 Internal Medicine Department, Hospital Universitario de La Santa Creu I Sant Pau, Barcelona, Spain

5 Internal Medicine Department, Hospital Santa Marina, ISS BioBizkaia, Bilbao, Spain

Published online: 06 September 2024

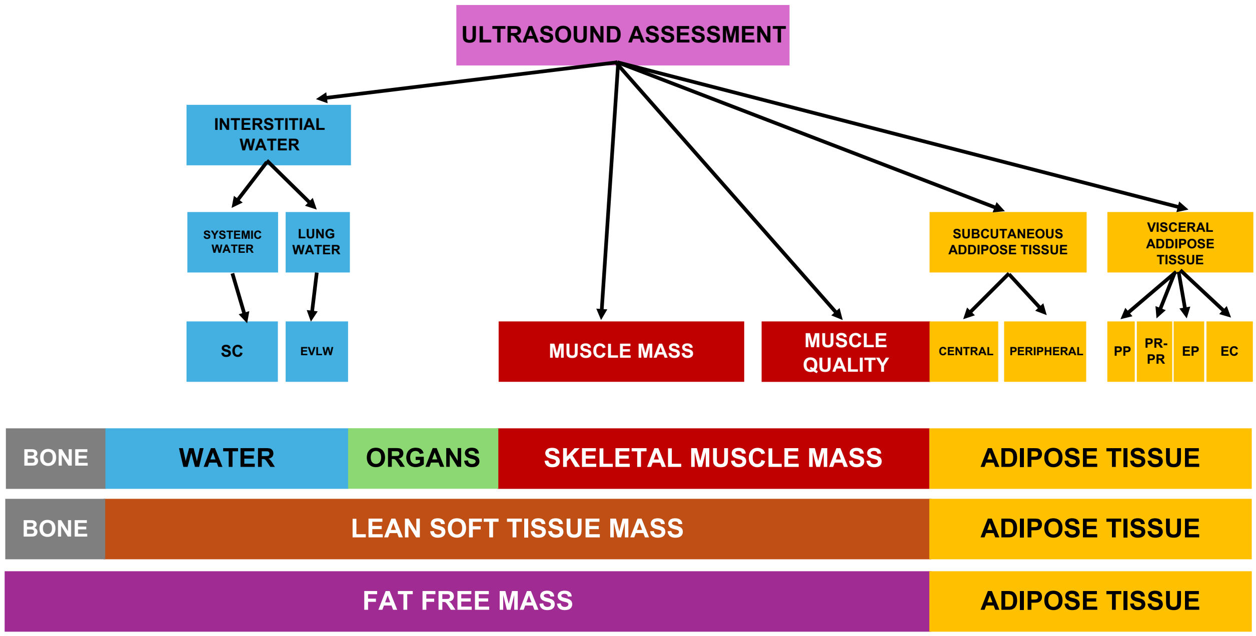

Fig. 1 What can be assessed using ultrasound and its relationship with body compartments. SC Systemic Congestion. EVLW Extravascular Lung Water. PP Preperitoneal adipose tissue. PR-PR Peri-renal and para-renal adipose tissue. EP Epicardial adipose tissue. EC Ectopic adipose tissue (hepatic steatosis and myosteatosis)

(GLIM) criteria were used to define and categorize malnutrition according to these guidelines [2]. The identification of individuals at risk for malnutrition can be achieved through various means, including the utilization of nutritional screening questionnaires, such as the Mini-Nutritional Assessment (MNA) [9], Malnutrition Universal Screening Tool (MUST) [10], and objective anthropometric assessment measures, such as body mass index or skinfold thickness, and functional tests, such as handgrip strength or gait speed, as well as combinations of these. However, these methods are insufficient or inaccurate for assessing body composition. Techniques, such as Dual-energy X-ray Absorptiometry (DEXA), Bioelectrical Impedance Analysis (BIA), Computed Tomography (CT), and Magnetic Resonance Imaging (MRI), offer better insights but are not always accessible or affordable. Ultrasound has gained interest for body composition assessment owing to its ease of use, cost-effectiveness, and reproducibility, allowing bedside evaluation of the muscle, fat, and extravascular water compartments. However, it lacks standardized measurements and criteria, hindering its validation for diagnosing malnutrition according to the GLIM criteria [11]. This review discusses the use of ultrasound in body composition assessments based on recent publications.

Skeletal muscle compartment

Disease-related malnutrition (DRM), sarcopenia, and sarcopenic obesity are prevalent conditions where their main pathophysiological features converge in the loss of function, quantity and quality of skeletal muscle mass [2, 12, 13]. This loss of muscular properties leads to adverse clinical outcomes and is an important prognostic factor of increasing interest in literature [5, 14]. Notably, it is imperative to evaluate skeletal muscle function in patients suspected of DRM, sarcopenia, or sarcopenic obesity, as ultrasound or any other diagnostic modality used for estimating skeletal muscle mass cannot measure muscle function, which is a crucial parameter for a comprehensive assessment of the patient's morpho-functional status [12, 15].

The classification criteria for these entities require the demonstration of skeletal muscle mass loss using validated techniques to establish a diagnosis. Although none of the most established consensus criteria (GLIM for DRM, EWGSOP2 for sarcopenia, or EASO for sarcopenic obesity) currently recognize ultrasound as a "validated" method for assessing skeletal muscle mass [2, 12, 13], there is growing interest in the dissemination of muscular ultrasound because of its advantages over other diagnostic alternatives (CT, MRI, BIA, or DEXA). Specifically, portability, availability, cost-effectiveness, and lack of radiation use make it a promising diagnostic tool for skeletal muscle mass assessment [16]. Ultrasound is an effective method for evaluating skeletal muscle mass, as it is both reproducible and user-friendly at the bedside, without a steep learning curve [17–19].

Muscle thickness, cross-sectional area (CSA), pennation angle (muscle fiber insertion angle with deep aponeurosis), fascicle length, and echo intensity were included in the initial research, whereas muscle volume, stiffness measured by shear-wave elastography (SWE), contraction potential, and microcirculation are promising markers of muscle assessment [20], conforming two types of ultrasound assessment: quantitative and qualitative. Quantitative evaluation (including muscle thickness and cross-sectional area) was compared with the gold standards (DEXA, MRI, and CT) and revealed a good correlation [17]. Little information is available regarding muscle volume and its relationship with functional parameters [21].

Qualitative methods include the pennation angle (in pennated muscles only), which is related to force-generating capacity [22] and has some evidence of correlation with gait speed [23]. Echo-intensity may reveal the presence of a fat-infiltrating muscle, known as myosteatosis. As a subjective and operator-dependent parameter may not be ideal for myosteatosis detection [24], although grayscale analysis can be used to standardize the measurement [25]. Changes in muscular composition lead to changes in tissue deformation and stiffness which can be assessed using SWE.

Most of these parameters are typically assessed with the aid of a multifrequency linear probe; however, caution must be taken when positioning it to prevent inappropriate insonation angles [24], as this could lead to errors in the measurement of muscle parameters. Additionally, it is important to minimize the pressure applied to the patient to ensure that no involuntary distortions are made in the measurement distances [26]. A curvilinear probe can be used with a relatively good correlation to the linear probe [27]; however, using the latter is advised [26]. The authors recommend performing the ultrasound evaluation with an appropriate ergonomic stance, the forearm rested in the patient's body to elude involuntary muscular compression, with a sufficient amount of coupling gel, and ensuring a proper insonation angle, as opposed to holding the probe by the cable or most proximal part, which could lead to an incorrect insonation angle. Inaccurate measurements depending on the pressure or insonation angle are shown in Fig. 2.

According to the most recent literature, up to 39 different muscles can be measured for muscle mass estimation

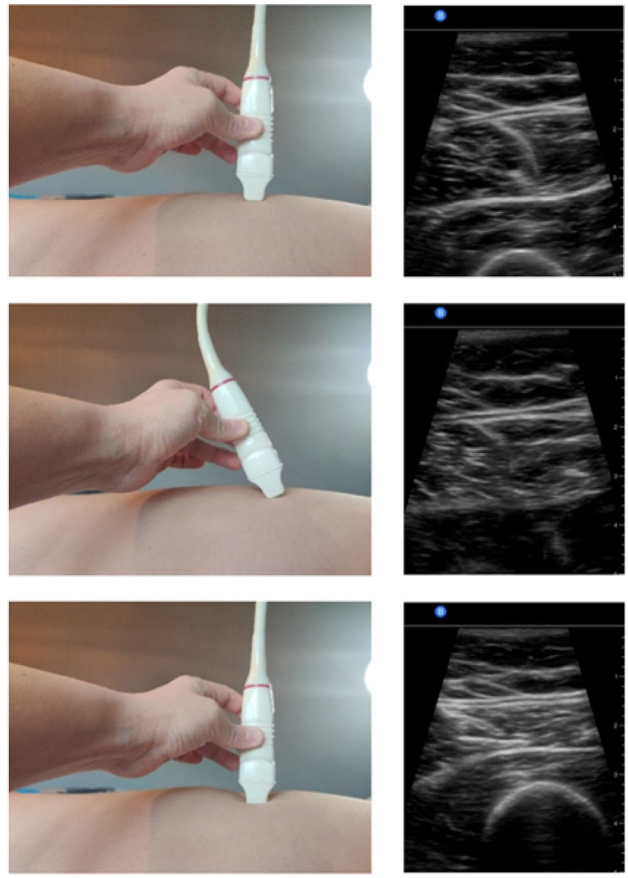

Fig. 2 Correlation between image, probe position, and pressure. The upper image shows the correct view of the rectus femoris muscle. The middle image depicts an incorrect insonation angle and distortion in the muscle appearance and thickness. The pressure applied to the muscle is transferred to the muscle to obtain a shrunken image with falsely small thickness, as shown in the lower image demonstrates

[20]. The use of different protocols and the measurement of different parameters challenge the role of skeletal muscle ultrasound in these scenarios Thus, it is imperative to undertake efforts towards the standardization of this technique [20, 28, 29]. Lower limb muscles account for the majority of studies assessing sarcopenia, as evidence suggests that mid-tight muscle mass shows good correlation with total body muscle mass [30]. The rectus femoris muscle (RFM) is a well-studied exponent of skeletal muscle mass [20].

Rectus femoris muscle

RFM is a pennate muscle that proximally attaches to the anterior inferior iliac spine and distally to the patella via the patellar tendon, running superficially along the anterior thigh. Unlike the adjacent muscles, it has a central aponeurosis, which makes it easily recognizable (Fig. 3). Previous studies have shown that RFM has a good correlation with total body muscle mass on MRI [30], DEXA, or BIA [31],

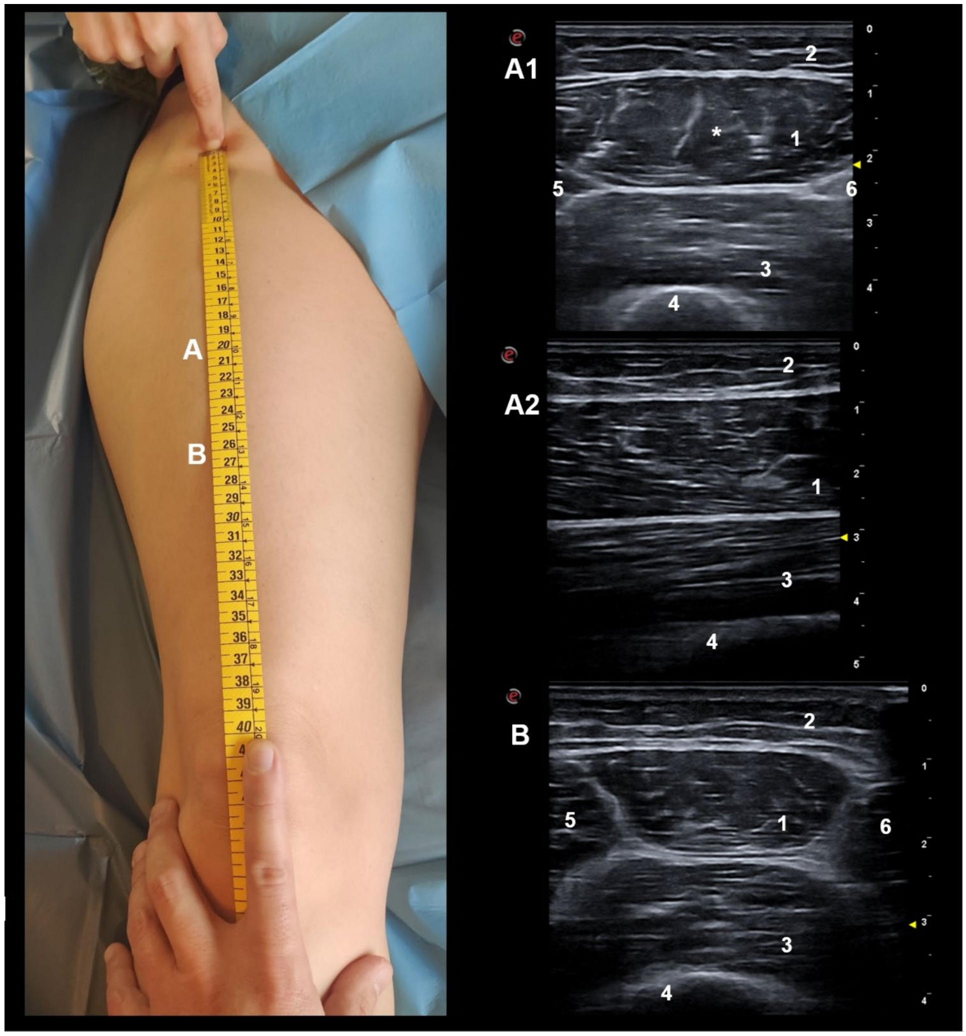

Fig. 3 Ultrasound of the RFM. Left image: determination of the point for measurement, halfway point (**A**), and two-thirds point (**B**). Right images: A1 Transverse section of the RFM at its halfway point. Note the central aponeurosis (asterisk) and how the lateral margins exceed the ultrasound field of view, preventing the measurement of the transverse axis (X-axis). A2: Longitudinal section of the RFM. Note the angle formed by the RFM fibers with the posterior fascia (pennation angle). B: Transverse section of the RFM at two-thirds point. Note that the diameters and areas are significantly smaller than those at the halfway point, with the central aponeurosis not visible. 1- RFM; 2- subcutaneous tissue; 3- vastus intermedius muscle; 4- femur; 5- vastus lateralis muscle; 6- vastus medialis muscle

as well as handgrip strength and anthropometric measurements such as calf circumference [11]. It is easily accessible and identifiable by ultrasound, and its evaluation has demonstrated excellent intra- and inter-observer correlations [18]. Therefore, RFM assessment has emerged as the most promising method for ultrasound study of sarcopenia.

RFM is measured using various protocols that primarily differ in the locations where the measurements are made. There is a reasonable consensus [26] that the patient should be positioned supine, with the lower limbs extended and relaxed, although some studies have performed the assessment in a seated position. The patient must have been rested before the examination. Measurement is recommended on the dominant side (usually the right leg), although significant asymmetries are uncommon [32]. To establish muscle length, the distance between the anterior superior iliac spine (or the greater trochanter) and the upper edge of the patella can be used as a reference [20, 26]. Measurements should be taken either at the midpoint of this distance or at the junction between the proximal two-thirds and distal third [20, 26]. RFM is thicker at the midpoint and tapers distally. Thus, at its midpoint, the muscle width may surpass the boundaries of the ultrasound window, preventing measurement of the transverse axis or cross-sectional area [20, 26]. This problem usually does not occur distally, where the muscle is narrower (Fig. 3). Currently, there is no evidence to recommend one measurement point over another, although reference values and cut-off points are not interchangeable and should not be used indiscriminately. When the measurement is taken at the midpoint of the RFM, panoramic vision and extended field-of-view software can expand the field-of-view to encompass the entire muscle.

Regardless of the chosen measurement point, in the transverse view, the anteroposterior diameter (Y-axis or muscle thickness, measured between the deep and superficial fascia) and laterolateral diameter (X-axis), as well as the muscle cross-sectional area and echo intensity pattern, will be recorded [26]. Visualization of the anteroposterior diameter along the Y-axis, pennation angle, and muscle fascicle length can be achieved by rotating the transducer by

90°and positioning it longitudinally relative to the muscle (see Fig. 3).

In recent years, numerous studies have demonstrated that sarcopenic patients and those presenting with DRM have smaller muscle thicknesses, cross-sectional areas, and pennation angles. The ratio between the X-axis and Y-axis also shows a good correlation with sarcopenia (the higher the X-axis/Y-axis ratio, the greater the probability of sarcopenia) [33]. Among these parameters, the muscle thickness (Y-axis) provides the most robust evidence. In any case, the primary obstacle to employing RFM ultrasound for assessing sarcopenia is the lack of adequately validated cut-off points that accurately distinguish patients with reduced muscle mass. Although a few noteworthy studies have been published recently, it is necessary to authenticate these findings and ascertain how these benchmark values behave in various populations. The proposed cut-off points in various studies and their diagnostic values are summarized in Table 1.

In practical terms, until standardized cut-off points are established, it will be necessary to interpret ultrasound measurements by considering the population being examined (e.g., geriatric and surgical patients), the specific location of the measurement (midpoint or distal third), the intended purpose of the measurement, and the whole clinical picture. Lower cut-off values will be more beneficial in older patients and when a high positive predictive value is needed, whereas higher values may be used in younger populations and/or when a high negative predictive value is required. Regardless of the absolute value of the measurements, evaluating the temporal evolution allows for assessing the improvement or deterioration of muscle mass, such as the decline associated with hospitalization or the response to functional rehabilitation treatment.

Echo intensity is also an important parameter in the assessment of RFM and allows for the identification of qualitative muscle alterations, such as myosteatosis and myofibrosis.

Other muscles

The vastus intermedius muscle arises from the front and lateral surfaces of the femur body in the upper two-thirds, sitting under the RFM, and from the lower part of the lateral intermuscular septum. Although close in relation to RFM, measuring the thickness of both muscles (quadriceps femoris thickness) or vastus intermedius thickness alone [32, 35] does not seem to provide better diagnostic performance than exclusively assessing RFM [37].

Among other lower-limb muscles, the medial gastrocnemius (MG) muscle shows a promising correlation with sarcopenia [37]. MG thickness is evaluated in a prone position, with legs extended and relaxed, and feet hanging off the examination bed. The muscle thickness is measured in the area where the largest cross-sectional area is observed on B-mode imaging. A tentative cut-off point of 1.5 cm showed good diagnostic performance (area under the curve 0.82) for sarcopenia (defined by DEXA) [38]. In outpatient geriatric patients, MG thickness < 1.23 mm (in both sexes) showed interesting diagnostic accuracy (AUC 0.9) for sarcopenia (according to EWGSOP2 criteria). Although promising, patient positioning could be a limiting factor depending on the patient's performance status.

One promising application is the use of ultrasonography to assess diaphragm thickness, which has been found to exhibit a moderate correlation with respiratory strength measured by mouth pressure manometry [39]. Additionally, this measurement has been suggested as a valuable prognostic marker for diseases characterized by dyspnea [40].

Elastography

SWE uses ultrasound imaging to measure the elasticity of tissues by analyzing the velocity of the shear waves (Fig. 4). It requires specialized ultrasound probes and software, which may limit the access to this technique. Tissue depth and surrounding tissue elasticity may influence SWE results [41], revealing that RFM is the ideal region of interest because of its greater distance to the femur. In elderly patients with type 2 diabetes and sarcopenia, SWE shows a lower stiffness of RFM than age-paired patients without sarcopenia, showing a promising tool for sarcopenia screening [42]. As muscle rigidity may reveal changes in muscle composition (and thus probably in muscle function and muscle weakness [43]), it shows a better correlation than RFM thickness or CSA with physical or muscle function in patients with chronic obstructive pulmonary disease [44]. There are some considerations for avoiding unreliable results in SWE such as using a minimal amount of coupling gel to avoid falsely increasing tissue stiffness [45], positioning the patient comfortably to elude involuntary muscle contraction and scanning superficial muscles [46]. Notably, a significant portion of the fluctuation in SWE might be attributed to age, and the conflicting results of different studies, where older individuals showed both higher and lower stiffness, warrant further investigation [47].

Fat compartment

Similar to muscle tissue, CT and MRI are the gold standard tests for measuring the fat compartment. However, as mentioned earlier, ultrasound is emerging as a reference technique for evaluating and assessing body composition because of its accessibility, reproducibility, and ability to facilitate much faster progress in research in this area.

Table 1 Proposed ultrasound cut-off points in the literature for determining low muscle mass in RFM

Author	Measurement	Cut-off values	Diagnostic value	Population
Rustani et al.[34]	Halfway point, supine	Muscle thickness Male 0,9 cm Female 0,7 cm	Sn 100% Sp 64% AUC 0,9 PPV 64% NPV 100%	119 hospitalized Internal Medicine patients, mean age 82.8 years
De Luis et al. [29]	Two thirds point, supine	For severe sarcopenia: Y-axis (MT) Male 0,86 cm Female 0,88 cm X-axis Male 3,78 cm Female 3,77 cm CSA Male 3,41 cm^2 Female 3,12 cm^2	Males Sn 75–95% Sp 62–77% AUC 0,73–0,82 PPV 9–15% NPV 98–99% Females Sn 54–95% Sp 50–77% AUC 0,56–0,60 PPV 5–6% NPV 98%	991 hospitalized patients (excluding ICU), mean age 58.5 years
Fukumoto et al. [35]	Halfway point, sitting position	Muscle thickness Male 1,51 cm Female 1,43 cm	Males Sn 69% Sp 84% AUC 0,775 Females Sn 60% Sp 67% AUC 0,654	204 Japanese community-dwelling patients, mean age 75.4 years
Barotsis et al. [32]	Halfway point, supine	M thickness Transverse 1,54 cm	Sn 69% Sp 65% AUC 0,67	94 outpatients, mean age 75,6 years
Wilkinson et al. [36]	Halfway point, sitting position	Cross-sectional area Male 8,9 cm^2 Female 5,7 cm^2	Males Sn 100% Sp 47% AUC 0,7 PPV 25% NPV 100% Females: Sn 100% Sp 71% AUC 0,9 PPV 22% NPV 100%	113 outpatients with chronic kidney disease (not on renal replacement), mean age 62 years
Ozturk et al (11)	Halfway point, supine	Muscle thickness Male 1,7 cm Female 1,13 cm Cross-sectional area Male 7,2 cm^2 Female 4 cm^2	Males (MT-CSA) Sn 86–100% Sp 54–60% AUC 0,74–0,76 PPV 26–32% NPV 95–100% Females (MT-CSA) Sn 80–100% Sp 85–80% AUC 0,84–0,94 PPV 36–36% NPV 98–100%	118 patients admitted to Internal Medicine, mean age 64 years

MT muscle thickness, *Sn* sensitivity, *Sp* specificity, *AUC* area under the curve, *PPV* positive predictive value, *NPV* negative predictive value, *Y-axis* anteroposterior diameter, *X-axis* side-lateral diameter, *CSA* cross-sectional area, *ICU* intensive care unit

Fat compartment ultrasound evaluation presents a more complex task than assessing muscle tissue because of the various types of fat tissue with distinct functions (regenerative, remodeling, nutritional, metabolic, immune, etc.) that exist in different anatomical locations [48], necessitating a more nuanced evaluation. This complexity makes

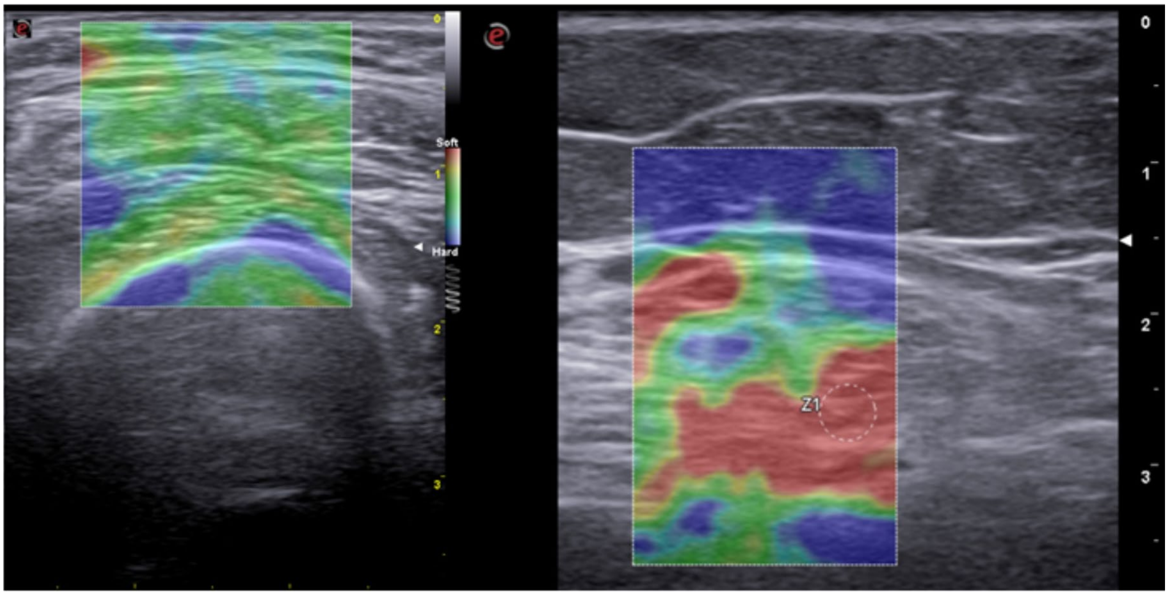

Fig. 4 SWE imaging of normal RFM (left image) and RFM with myosteatosis (right image), where a decrease in muscle stiffness can be noted by the predominance of red and yellow tones in the elastographic color map

the complete assessment of fat compartments using ultrasound challenging.

Two primary types of adipose tissue exist: brown, characterized by its multiloculated structure and primary function of heat production, and white, characterized by its uniloculated structure and primary function of energy storage [49]. Ultrasonography to assess body composition focuses on the latter type of adipose tissue.

White adipose tissue is categorized into two primary regions: central (located in the trunk, mainly the abdomen) and peripheral (in the limbs). White adipose tissue is further subdivided into visceral (surrounding various organs and viscera, including the omentum and mesentery) and subcutaneous (beneath the skin) compartments. The subcutaneous adipose tissue is divided into superficial and deep layers. Additionally, fat can accumulate within or infiltrate various organs, resulting in myosteatosis and hepatic steatosis.

Below, we provide a more detailed explanation of the different locations and characteristics of fat compartments.

Visceral fat

Visceral fat surrounds organs and viscera and is therefore, by definition, central fat. It is divided into preperitoneal, peri- and para-renal, epicardial, and intra-abdominal fat. Visceral fat is correlated with the presence of cardiovascular disease risk factors, including comorbidity variables associated with obesity, such as elevated levels of triglycerides, LDL cholesterol, and apolipoprotein B, as well as low levels of HDL cholesterol, increased insulin resistance, and hyperinsulinemia. Additionally, the size of this compartment is linked to changes in the serum concentrations of leptin, TNF-α, and sex hormones.

Preperitoneal fat

This is located beneath the rectus abdominis muscles and up to the peritoneum, and should be measured with a linear probe from the linea alba to the parietal leaf of the peritoneum. Owing to its accessibility and ease of acquisition, this is the most studied visceral fat on ultrasound, and it can be measured at two points:

1. Just below the xiphoid process (maximum preperitoneal fat), in a longitudinal section, as the ribs may interfere with contact between the probe surface and skin if performed in a transverse section.
2. At the midpoint of an imaginary line connecting the xiphoid process and navel, in the transverse section.

In a pilot study conducted on hospitalized patients, the maximum preperitoneal fat was found to be related to the number of hospital days (the less fat, the longer the hospital stay) and constituted an independent prognostic variable for hospitalized patients [50].

Peri- and pararenal fat

This is the visceral fat surrounding the kidney. Anatomically, perirenal fat is more external, located between the intermediate fascia of the retroperitoneum and the renal fascia, whereas para-renal fat is found inside the renal fascia. The thickness of peri- and para-renal fat measured by ultrasound correlates better with total and visceral fat than body mass index (BMI), waist circumference (WC), and other obesity indices. Additionally, it has been described to have a local mechanical and paracrine effects on the kidneys [51]. In patients with type 2 diabetes mellitus, it is more closely related to glomerular filtration rate than other obesity-related indicators and could therefore be a predictor of chronic kidney disease (CKD) in this population [52]. For its assessment, a low-frequency convex probe is necessary, with the patient in a supine or seated position, and an imaging section conducted along the axillary line in a coronal orientation.

Epicardial fat

Epicardial and pericardial fat are present around the heart, but epicardial fat has cardiovascular implications [53], which is the focus of this discussion. Epicardial fat secretes bioactive molecules that exert modulatory effects on the myocardium. Anatomically and echocardiographically, it is located between the myocardium and visceral layer of the pericardium, covering approximately 80% of the heart's surface [54].

Intra-abdominal fat

Intra-abdominal fat is present in both abdominal and pelvic regions. It is categorized into two types: intraperitoneal fat and extraperitoneal fat. Intraperitoneal fat includes omental fat, which is located in the greater omentum, and mesenteric fat. Extraperitoneal fat comprises retroperitoneal fat, which is situated between the peritoneum and transverse fascia and includes peri- and para-renal fat, as well as prevertebral fat. Additionally, extraperitoneal fat exists between pelvic organs, including parametrial, retropubic, paravesical, retrouterine, pararectal, and retrorectal fat [49]. Although important, intra-abdominal fat is not routinely measured by ultrasound as part of body composition evaluations, with the exception of peri- and para-renal fat, which are more standardized).

Subcutaneous fat

Subcutaneous fat is located beneath the dermis and usually covers the muscles. It can be centrally located (in the trunk) or peripherally located (in the extremities) and has both superficial and deep components separated by the circumferential subcutaneous fascia, although they are often indistinguishable. There is no consensus on whether differences exist in the metabolic implications of each component [49].

Central

This fat is located in the thorax and abdomen and has greater implications for increasing cardiovascular and metabolic risks than peripheral fat, because it is associated with a higher risk of insulin resistance [55]. The fat measured ultrasonographically is located in the abdomen between the skin and linea alba. The minimum central subcutaneous tissue (in the subxiphoid region) and the maximum (at various locations, such as the midpoint of the line connecting the xiphoid process and the navel or 2 cm cranial or caudal to the navel) can be measured.

Peripheral

This fat is located in the extremities and can be assessed at any point. However, ultrasonography is generally employed to gauge the rectus femoris and concurrently evaluate subcutaneous adipose tissue in this particular area.

Ectopic fat

Myosteatosis

Myosteatosis is a condition characterized by the infiltration of intra- and intermuscular fat, which results in the reduction of muscle strength and quality. This leads to poorer muscle functionality and survival, as previously stated [56]. Fat infiltration causes a loss of muscle fiber definition and, owing to its association with lower functionality, results in a smaller muscle size (not necessarily thickness). This has been demonstrated in thigh muscles, particularly the quadriceps, which is why the evaluation of echo intensity in RFM is crucial. However, this has not been observed in calf muscles [57]. Myosteatosis can occur in both obesity and aging, and it can be detected through ultrasonography, which displays increased echogenicity in affected muscles. Although attempts have been made to quantify it in grayscale, there are significant differences between ultrasound machines, which complicate the standardization and comparability of measurements [20, 26]. Qualitative assessment is possible using the Heckmatt scale, which establishes four grades depending on the loss of muscular structure and the underlying bone ultrasound reflection [58]. Distinguishing between extremes may be relatively straightforward, but discerning subtle variations can be challenging [59]. In our opinion, in a simplistic and subjective (albeit pragmatic) manner, loss of visualization of the central aponeurosis of the RFM could indicate the presence of myosteatosis/myofibrosis (Fig. 5). This suggests a relevant change in muscle metabolic function and health, which may necessitate comparable management through lifestyle modifications and physical therapy [60]. As mentioned above, computer-aided systems can

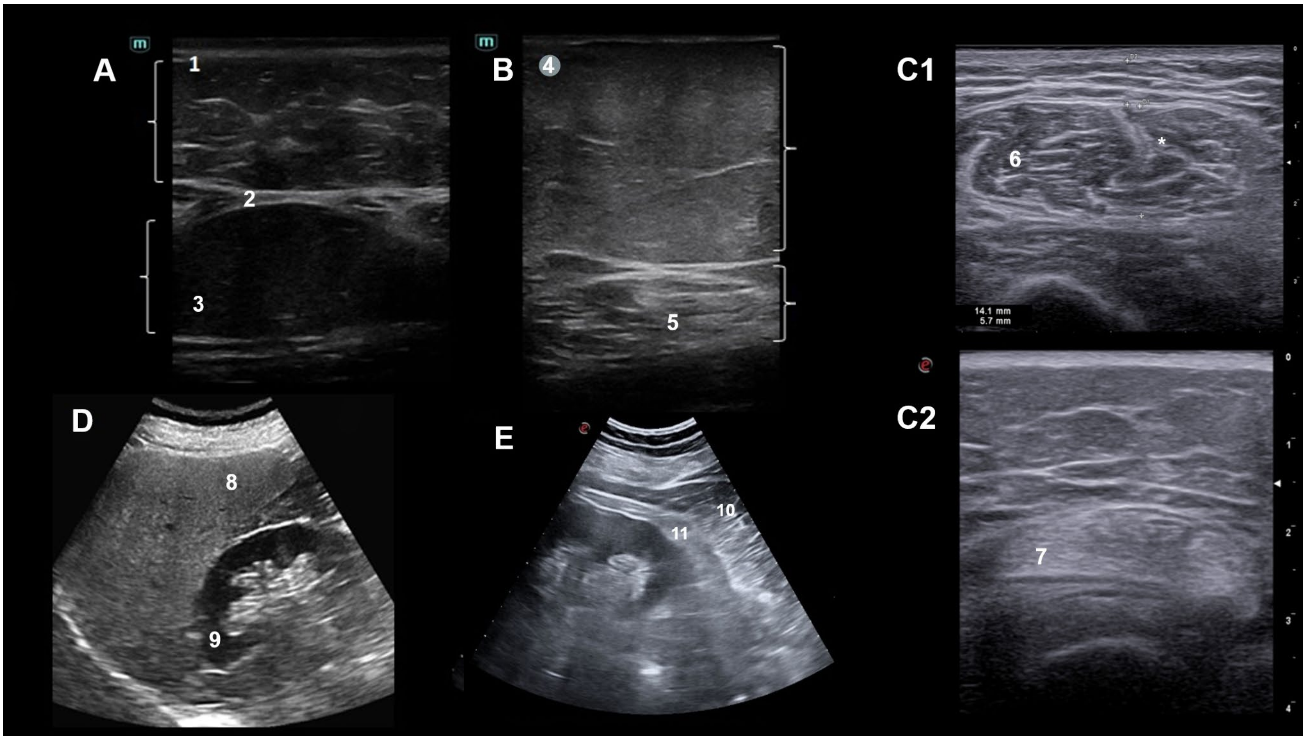

Fig. 5 A: Image at the midpoint of the imaginary line between the xiphoid process and navel, showing the skin, central subcutaneous fat (1), linea alba (2) between the rectus abdominis muscles, and preperitoneal fat (3). B: Image taken at the distal third of the imaginary line between the anterior superior iliac spine and the upper border of the patella, showing the peripheral adipose panicle (4) and the RFM reduced in size with fat infiltration (5) in a patient with sarcopenic obesity. C1: Normal RFM (6) with central aponeurosis (asterisk) is clearly visible. C2: RFM with myosteatosis (7), where the central aponeurosis is not clearly visible. D: Image taken at the right midaxillary line, showing increased echogenicity of the liver parenchyma (8) compared to the renal cortex (9), as well as difficulty in visualizing the posterior segments (hepatic steatosis). E: Image showing the kidney, perirenal fat (10), and para-renal fat (11) bounded by the intermediate fascia of the retroperitoneum and the renal fascia

standardize measurements and increase echo intensity validity and reproducibility.

Hepatic steatosis

This is the accumulation of fat in the liver and is a component of the metabolic syndrome. Ultrasonographically, it appears as increased echogenicity of the liver parenchyma when compared to the renal cortex or spleen, and loss of definition or non-visualization of the posterior segments and deep structures, such as the diaphragm and vessels [61]. It is classified as mild, moderate, or severe. Ultrasound has very good accuracy in moderate-to-severe steatosis compared to other imaging tests [62].

Water compartment

Ultrasound does not allow the direct evaluation of body water distribution. Nevertheless, it can aid in the accurate detection of extravascular water in cavities, such as ascites and pleural effusion [63]. In selected clinical contexts, these findings may suggest congestion and, therefore, an expansion of the extracellular volume. Similarly, interstitial lung water, known as Extravascular Lung Water (EVLW), can be qualitatively evaluated by the presence of B-line artifacts, which exhibit an anterior, bilateral, and symmetrical distribution, along with a regular and homogeneous pleural line [64]. The presence or absence of pulmonary congestion should be sufficient to modify treatment plans, even though EVLW is quantitatively measured by other means, such as transpulmonary thermodilution systems [65].

The estimation of intravascular water volume by ultrasound is not feasible; however, it can be approximated by evaluating systemic venous congestion using innovative techniques, such as multidimensional analysis of the inferior vena cava, suprahepatic, portal, and renal hemodynamics. This allows the assessment of improvement or deterioration, which appears to be related to congestion-induced renal failure [66].

As part of a comprehensive clinical evaluation, ultrasonography can help determine the patient's ability to tolerate fluid therapy. This question is distinct from the assessment of body water distribution, but the methods described above are accurate in identifying excess body water. Examples of ultrasound assessment of the water compartment are shown in supplementary material.

Conclusions

The assessment of body composition is crucial for evaluating nutritional status and sarcopenia. Typically, this involves the use of costly or less accessible tests, such as DEXA, BIA, CT, or MRI. However, ultrasound offers a more accessible and cost-effective alternative without radiation exposure and has a relatively short learning curve. Ultrasound has proven useful in analyzing body composition, including the muscle, fat, and water compartments. Recent advancements have enhanced the techniques and interpretation of ultrasound findings, particularly with respect to muscle mass. Ultrasound is now recognized as a valuable complement to the assessment of nutrition-related sarcopenia, and as an objective tool for patient follow-up.

The specific changes in muscle characteristics that occur as a result of age or disease necessitate the development of customized cut-off points. It is essential to aim for higher positive or negative predictive values, depending on the clinical scenario and pre-test probabilities for sarcopenia or malnutrition. This approach is similar to other medical applications of ultrasound, in which the goal is to achieve accurate diagnostic results. Computer-assisted measurements of echo-intensity or SWE can improve the reliability of intra- and inter-operator variability and mitigate the differences in ultrasound machine settings.

Ultrasound enables detailed assessment of various fat compartments with significant metabolic implications, making it a promising tool for cardiovascular risk prediction. Future research should focus on larger trials with external validity, encompassing diverse ethnic and age groups, and relevant cardiometabolic endpoints.

Currently, there are no adequately validated cut-off points for diagnosing and classifying patients based on ultrasound findings. These cut-off points should be compared with existing gold standard techniques and demonstrate correlations with clinical outcomes. Standardized criteria, such as those from GLIM [2], EWGSOP2 [12], and EASO [13], should be used to ensure consistency in future studies. Given the growing interest in ultrasound, many current limitations and uncertainties are expected to be resolved in the near future.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11739-024-03756-8.

Data availability As the article is a literature review, no data availability is applicable.

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

Human and animal rights statement and Informed consent As the article is a literature review, no informed consent or ethical comitee consultation is applyable.

References

1. Wang ZM, Pierson RN Jr, Heymsfield SB (1992) The five-level model: a new approach to organizing body-composition research. Am J Clin Nutr 56(1):19–28
2. Cederholm T, Jensen GL, Correia MITD, Gonzalez MC, Fukushima R, Higashiguchi T et al (2019) GLIM criteria for the diagnosis of malnutrition—A consensus report from the global clinical nutrition community. Clin Nutr Edinb Scotl 38(1):1–9
3. Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyère O, Cederholm T et al (2019) Sarcopenia: revised European consensus on definition and diagnosis. Age Ageing 48(1):16–31
4. Yeung SSY, Reijnierse EM, Pham VK, Trappenburg MC, Lim WK, Meskers CGM et al (2019) Sarcopenia and its association with falls and fractures in older adults: a systematic review and meta-analysis. J Cachexia Sarcopenia Muscle 10(3):485–500
5. Liu P, Hao Q, Hai S, Wang H, Cao L, Dong B (2017) Sarcopenia as a predictor of all-cause mortality among community-dwelling older people: a systematic review and meta-analysis. Maturitas 103:16–22
6. Neeland IJ, Ross R, Després JP, Matsuzawa Y, Yamashita S, Shai I et al (2019) Visceral and ectopic fat, atherosclerosis, and cardiometabolic disease: a position statement. Lancet Diabetes Endocrinol 7(9):715–25
7. Thibault R, Abbasoglu O, Ioannou E, Meija L, Ottens-Oussoren K, Pichard C et al (2021) ESPEN guideline on hospital nutrition. Clin Nutr Edinb Scotl 40(12):5684–5709
8. Sheean P, Gonzalez MC, Prado CM, McKeever L, Hall AM, Braunschweig CA (2020) American Society for Parenteral and Enteral Nutrition Clinical Guidelines: the validity of body composition assessment in clinical populations. JPEN J Parenter Enteral Nutr 44(1):12–43
9. Kaiser MJ, Bauer JM, Ramsch C, Uter W, Guigoz Y, Cederholm T et al (2009) Validation of the Mini Nutritional Assessment short-form (MNA®-SF): a practical tool for identification of nutritional status. JNHA—J Nutr Health Aging 13(9):782
10. Elia M, British Association for Parenteral and Enteral Nutrition Advisory Group on Malnutrition. Guidelines for detection and management of malnutrition. Maidenhead: BAPEN Maidenhead; 2000.
11. Ozturk Y, Deniz O, Coteli S, Unsal P, Dikmeer A, Burkuk S et al (2022) Global Leadership Initiative on Malnutrition criteria with different muscle assessments including muscle ultrasound with hospitalized internal medicine patients. JPEN J Parenter Enteral Nutr 46(4):936–45
12. Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyère O, Cederholm T et al (2019) Sarcopenia: revised European consensus on definition and diagnosis. Age Ageing 48(1):16–31
13. Donini LM, Busetto L, Bischoff SC, Cederholm T, Ballesteros-Pomar MD, Batsis JA et al (2022) Definition and diagnostic

criteria for sarcopenic obesity: ESPEN and EASO consensus statement. Obes Facts 15(3):321–35
14. Mareschal J, Achamrah N, Norman K, Genton L (2019) Clinical value of muscle mass assessment in clinical conditions associated with malnutrition. J Clin Med 8(7):1040
15. Beaudart C, McCloskey E, Bruyère O, Cesari M, Rolland Y, Rizzoli R et al (2016) Sarcopenia in daily practice: assessment and management. BMC Geriatr 16(1):170–170
16. Ceniccola GD, Castro MG, Piovacari SMF, Horie LM, Corrêa FG, Barrere APN et al (2019) Current technologies in body composition assessment: advantages and disadvantages. Nutrition 62:25–31
17. Nijholt W, Scafoglieri A, Jager-Wittenaar H, Hobbelen JSM, van der Schans CP (2017) The reliability and validity of ultrasound to quantify muscles in older adults: a systematic review. J Cachexia Sarcopenia Muscle 8(5):702–12
18. Takahashi Y, Fujino Y, Miura K, Toida A, Matsuda T, Makita S (2021) Intra- and inter-rater reliability of rectus femoris muscle thickness measured using ultrasonography in healthy individuals. Ultrasound J 13(1):21
19. Zaidman CM, Wu JS, Wilder S, Darras BT, Rutkove SB (2014) Minimal training is required to reliably perform quantitative ultrasound of muscle. Muscle Nerve 50(1):124–8
20. Perkisas S, Bastijns S, Baudry S, Bauer J, Beaudart C, Beckwée D et al (2021) Application of ultrasound for muscle assessment in sarcopenia: 2020 SARCUS update. Eur Geriatr Med 12(1):45–59
21. Merrigan JJ, White JB, Hu YE, Stone JD, Oliver JM, Jones MT (2018) Differences in elbow extensor muscle characteristics between resistance-trained men and women. Eur J Appl Physiol 118(11):2359–2366
22. Atkinson RA, Srinivas-Shankar U, Roberts SA, Connolly MJ, Adams JE, Oldham JA et al (2010) Effects of testosterone on skeletal muscle architecture in intermediate-frail and frail elderly men. J Gerontol A Biol Sci Med Sci 65(11):1215–9
23. Zhu S, Lin W, Chen S, Qi H, Wang S, Zhang A et al (2019) The correlation of muscle thickness and pennation angle assessed by ultrasound with sarcopenia in elderly Chinese community dwellers. Clin Interv Aging 14:987–96
24. Dankel SJ, Abe T, Bell ZW, Jessee MB, Buckner SL, Mattocks KT et al (2020) The Impact of Ultrasound Probe Tilt on Muscle Thickness and Echo-Intensity: A Cross-Sectional Study. J Clin Densitom Off J Int Soc Clin Densitom. 23(4):630–8
25. Watanabe Y, Yamada Y, Fukumoto Y, Ishihara T, Yokoyama K, Yoshida T et al (2013) Echo intensity obtained from ultrasonography images reflecting muscle strength in elderly men. Clin Interv Aging 8:993–8
26. Perkisas S, Baudry S, Bauer J, Beckwée D, De Cock AM, Hobbelen H et al (2018) Application of ultrasound for muscle assessment in sarcopenia: towards standardized measurements. Eur Geriatr Med 9(6):739–757
27. Hammond K, Mampilly J, Laghi FA, Goyal A, Collins EG, McBurney C et al (2014) Validity and reliability of rectus femoris ultrasound measurements: comparison of curved-array and linear-array transducers. J Rehabil Res Dev 51(7):1155–1164
28. García-Almeida JM, García-García C, Vegas-Aguilar IM, Ballesteros Pomar MD, Cornejo-Pareja IM, Fernández Medina B, et al. Nutritional ultrasound®: Conceptualisation, technical considerations and standardisation. Endocrinol Diabetes Nutr [Internet]. 13 de julio de 2022; Disponible en: https://www.sciencedirect.com/science/article/pii/S2530016422001471
29. de Luis RD, García Almeida JM, Bellido Guerrero D, Guzmán Rolo G, Martín A, Primo Martín D et al (2024) Ultrasound cut-off values for rectus Femoris for detecting Sarcopenia in patients with nutritional risk. Nutrients 16(11):1552
30. Jung Lee S, Janssen I, Heymsfield SB, Ross R (2004) Relation between whole-body and regional measures of human skeletal muscle. Am J Clin Nutr 80(5):1215–21
31. Berger J, Bunout D, Barrera G, de la Maza MP, Henriquez S, Leiva L et al (2015) Rectus femoris (RF) ultrasound for the assessment of muscle mass in older people. Arch Gerontol Geriatr agosto de 61(1):33–38
32. Barotsis N, Galata A, Hadjiconstanti A, Panayiotakis G (2020) The ultrasonographic measurement of muscle thickness in sarcopenia. A prediction study. Eur J Phys Rehabil Med 56(4):427–37
33. López-Gómez JJ, García-Beneitez D, Jiménez-Sahagún R, Izaola-Jauregui O, Primo-Martín D, Ramos-Bachiller B et al (2023) Nutritional ultrasonography, a method to evaluate muscle mass and quality in morphofunctional assessment of disease related malnutrition. Nutrients 15(18):3923
34. Rustani K, Kundisova L, Capecchi PL, Nante N, Bicchi M (2019) Ultrasound measurement of rectus femoris muscle thickness as a quick screening test for sarcopenia assessment. Arch Gerontol Geriatr 83:151–4
35. Fukumoto Y, Ikezoe T, Taniguchi M, Yamada Y, Sawano S, Minani S et al (2021) Cut-off values for lower limb muscle thickness to detect low muscle mass for sarcopenia in older adults. Clin Interv Aging 16:1215–1222
36. Wilkinson TJ, Gore EF, Vadaszy N, Nixon DGD, Watson EL, Smith AC (2021) Utility of ultrasound as a valid and accurate diagnostic tool for sarcopenia. J Ultrasound Med 40(3):457–67
37. Fu H, Wang L, Zhang W, Lu J, Yang M (2023) Diagnostic test accuracy of ultrasound for sarcopenia diagnosis: a systematic review and meta-analysis. J Cachexia Sarcopenia Muscle 14(1):57–70
38. Wang J, Hu Y, Tian G (2018) Ultrasound measurements of gastrocnemius muscle thickness in older people with sarcopenia. Clin Interv Aging 13:2193–2199
39. Holtzhausen S, Unger M, Lupton-Smith A, Hanekom S (2018) An investigation into the use of ultrasound as a surrogate measure of diaphragm function. Heart Lung J Crit Care 47(4):418–24
40. Santana PV, Cardenas LZ, de Albuquerque ALP, de Carvalho CRR, Caruso P (2020) Diaphragmatic ultrasound: a review of its methodological aspects and clinical uses. J Bras Pneumol Publicacao Of Soc Bras Pneumol E Tisilogia 46(6):e20200064
41. Bastijns S, De Cock AM, Vandewoude M, Perkisas S (2020) Usability and pitfalls of shear-wave elastography for evaluation of muscle quality and its potential in assessing sarcopenia: a review. Ultrasound Med Biol 46(11):2891–2907
42. Chen ZT, Jin FS, Guo LH, Li XL, Wang Q, Zhao H et al (2023) Value of conventional ultrasound and shear wave elastography in the assessment of muscle mass and function in elderly people with type 2 diabetes. Eur Radiol 33(6):4007–15
43. Alfuraih AM, Tan AL, O'Connor P, Emery P, Wakefield RJ (2019) The effect of ageing on shear wave elastography muscle stiffness in adults. Aging Clin Exp Res 31(12):1755–1763
44. Deng M, Zhou X, Li Y, Yin Y, Liang C, Zhang Q et al (2021) Ultrasonic elastography of the rectus femoris, a potential tool to predict sarcopenia in patients with chronic obstructive pulmonary disease. Front Physiol 12:783421
45. Kot BCW, Zhang ZJ, Lee AWC, Leung VYF, Fu SN (2012) Elastic modulus of muscle and tendon with shear wave ultrasound elastography: variations with different technical settings. PLoS ONE 7(8):e44348
46. Drakonaki EE, Allen GM, Wilson DJ (2012) Ultrasound elastography for musculoskeletal applications. Br J Radiol 85(1019):1435–45
47. Janczyk EM, Champigny N, Michel E, Raffaelli C, Annweiler C, Zory R et al (2020) Sonoelastography to assess muscular stiffness among older adults and its use for the diagnosis of sarcopenia: a systematic review. Ultraschall Med 42(06):634–42

48. Zwick RK, Guerrero-Juarez CF, Horsley V, Plikus MV (2018) Anatomical, physiological, and functional diversity of adipose tissue. Cell Metab 27(1):68–83
49. Pérez Miguelsanz MAJ, Cabrera Parra W, Varela Moreiras G, Garaulet M (2010) Distribución regional de la grasa corporal. Uso de técnicas de imagen como herramienta de diagnóstico nutricional. Nutr Hosp 25(2):207–23
50. Marín-Baselga R, Sanz-Ortega C, Platero-Dueñas L, Sorriguieta-Torre R, Palma-Milla S, Tung-Chen Y (2023) Nutritional assessment by ultrasound of the rectus femoris and preperitoneal adipose tissue as predictors of hospitalized patient complications. Rev Clin Esp 223(10):640–646
51. Geraci G, Zammuto MM, Mattina A, Zanoli L, Geraci C, Granata A et al (2018) Para-perirenal distribution of body fat is associated with reduced glomerular filtration rate regardless of other indices of adiposity in hypertensive patients. J Clin Hypertens Greenwich Conn 20(10):1438–46
52. Xu S, Ma J, Zheng Y, Ren R, Li W, Zhao W et al (2023) Para-perirenal fat thickness is associated with reduced glomerular filtration rate regardless of other obesity-related indicators in patients with type 2 diabetes mellitus. PLoS ONE 18(10):e0293464
53. Iacobellis G (2009) Epicardial and pericardial fat: close, but very different. Obes Silver Spring Md 17(4):626–627
54. Rabkin SW (2007) Epicardial fat: properties, function and relationship to obesity. Obes Rev Off J Int Assoc Study Obes 8(3):253–61
55. Zhang M, Hu T, Zhang S, Zhou L (2015) Associations of different adipose tissue depots with insulin resistance: a systematic review and meta-analysis of observational studies. Sci Rep 5(1):18495
56. Reinders I, Murphy RA, Brouwer IA, Visser M, Launer L, Siggeirsdottir K et al (2016) Muscle quality and myosteatosis: novel associations with mortality risk: the age, gene/environment susceptibility (AGES)-Reykjavik study. Am J Epidemiol 183(1):53–60
57. Reinders I, Murphy RA, Koster A, Brouwer IA, Visser M, Garcia ME et al (2015) Muscle quality and muscle fat infiltration in relation to incident mobility disability and gait speed decline: the age, gene/environment susceptibility-Reykjavik study. J Gerontol Ser A 70(8):1030–6
58. Heckmatt JZ, Pier N, Dubowitz V (1988) Real-time ultrasound imaging of muscles. Muscle Nerve 11(1):56–65
59. Moreta MC, Fleet A, Reebye R, McKernan G, Berger M, Farag J et al (2020) Reliability and validity of the modified heckmatt scale in evaluating muscle changes with ultrasound in spasticity. Arch Rehabil Res Clin Transl. https://doi.org/10.1016/j.arrct.2020.100071
60. Correa-de-Araujo R, Addison O, Miljkovic I, Goodpaster BH, Bergman BC, Clark RV, et al. Myosteatosis in the Context of Skeletal Muscle Function Deficit: An Interdisciplinary Workshop at the National Institute on Aging. Front Physiol. 2020;11. Disponible en: https://www.frontiersin.org/journals/physiology/articles/https://doi.org/10.3389/fphys.2020.00963
61. Lewis JR, Mohanty SR (2010) Nonalcoholic fatty liver disease: a review and update. Dig Dis Sci marzo de 55(3):560–578
62. Hernaez R, Lazo M, Bonekamp S, Kamel I, Brancati FL, Guallar E et al (2011) Diagnostic accuracy and reliability of ultrasonography for the detection of fatty liver: a meta-analysis. Hepatol Baltim Md 54(3):1082–90
63. Yousefifard M, Baikpour M, Ghelichkhani P, Asady H, Shahsavari Nia K, Moghadas Jafari A et al (2016) Screening performance characteristic of ultrasonography and radiography in detection of pleural effusion; a meta-analysis. Emerg Tehran Iran 4(1):1–10
64. Lichtenstein DA (2014) Lung ultrasound in the critically ill. Ann Intensive Care 4(1):1
65. Jozwiak M, Teboul JL, Monnet X (2015) Extravascular lung water in critical care: recent advances and clinical applications. Ann Intensive Care 5(1):38
66. Beaubien-Souligny W, Rola P, Haycock K, Bouchard J, Lamarche Y, Spiegel R et al (2020) Quantifying systemic congestion with Point-Of-Care ultrasound: development of the venous excess ultrasound grading system. Ultrasound J 12(1):16–16